TRD Overview and Requirements

CBM-TRD
TDR Review Meeting
GSI Darmstadt, Germany
March 14+15, 2017

Christoph Blume
University of Frankfurt

Overview

Physics objectives

Design considerations

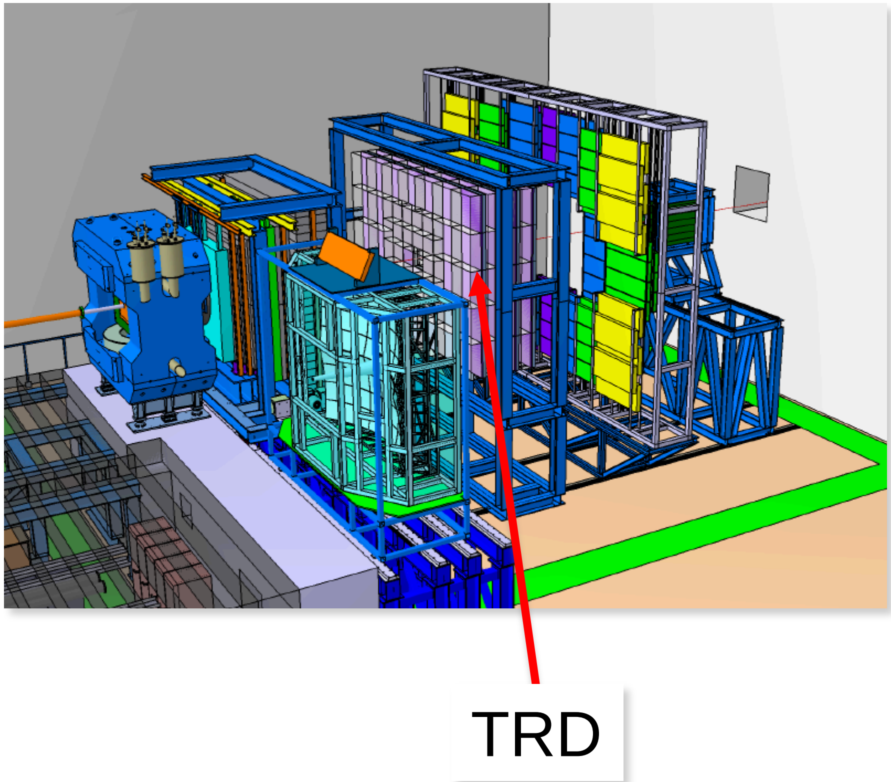
TRD baseline design (SIS100)

Performance studies

Intermediate mass dielectrons

Fragments

Quarkonia (J/ψ)



Physics Objectives (SIS100)

Intermediate mass dileptons
Mass range between $m(\phi)$ and $m(J/\psi)$
Access to thermal radiation from hot and dense fireball

Fragments
Important basis for hypernuclei and anti-nuclei program

Quarkonia (J/ψ)
Important probe for deconfined matter (J/ψ-suppression)

TRD will be essential !

Low mass vector mesons
Medium induced modification of hadron properties
Chiral phase transition and the origin of hadron masses

Photons
Thermal properties of the early stages of fireball evolution
Measurement via conversion ($\gamma \rightarrow e^+e^-$)

TRD will help

Design Considerations

Pion rejection capability
Driven by dileptons and J/ψ

Pion suppression factor of 10−20 (@ 90% e-efficiency) for p > 6 GeV/c needed

Charged particle identification
Should be able to separate fragments heavier than protons ($1/\beta^2$-region)

dE/dx-Resolution around 30 % sufficient

Tracking capabilities
Track matching between STS and TOF, important for clean hadron ID with TOF
Charge measurement (Z = 1, 2) essential for momentum determination

Good space point resolution required (around 300 μm)
Material budget should be kept minimal (secondaries + multiple scattering)

Design Considerations

Interaction rates

Driven by dileptons and J/ψ (interaction rates up to 10 MHz)

Fast detector, with signal collection times below 0.3 μs
Gas volume as thin as possible (still should provide sufficient TR absorption!)
Pad granularity small enough to keep data rate low (occupancy, FEE)

Tracking of muons

TRD is foreseen as last tracking station in MUCH setup

No particle ID needed
Relatively low multiplicities (behind absorber)
TRD acceptance should match MUCH

TRD Baseline Design (SIS100)

General TRD layout

Four detector layers

Radiator: PE foam-foil arrangement

Readout: MWPCs (3.5 + 3.5 + 5.0 mm)

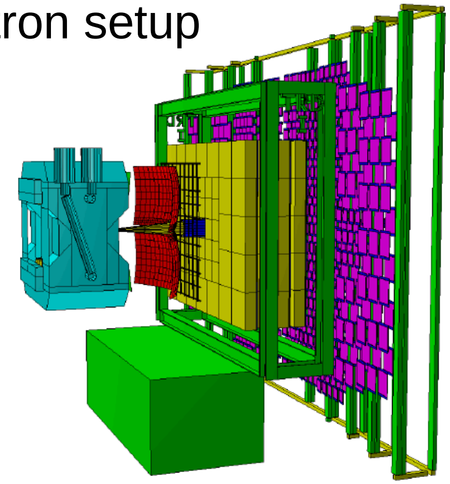
200 detector modules in total (radiator + MWPC)
in two different sizes (57 × 57 cm^2 and 95 × 95 cm^2)

Six different pad plane layouts
(pad areas between 1 cm^2 and 11 cm^2)

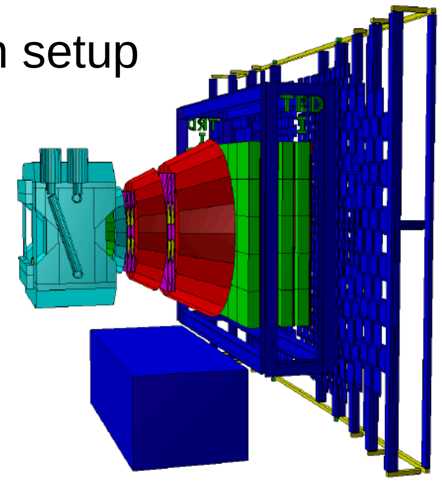
Readout with online data reduction
+ feature extraction (SPADIC)

Movable along beam direction
to fit TRD into different CBM setups

Electron setup



Muon setup



Design Parameters

Pseudo-rapidity coverage	$0.89 < \eta < 3.74$
Azimuthal coverage	2π
z position	$4.1\,\mathrm{m} < z < 5.9\,\mathrm{m}$
Maximal height (station 1)	4.75 m
Maximal width (station 1)	6.65 m
Gas volume	$1.37\,\mathrm{m}^3$
Total thickness of one layer	0.45 m
Number of stations	1
Number of layers	4
Total number of modules	200
Number of readout channels	287744
Dimension of large module	$95 \times 95\,\mathrm{cm}^2$
Dimension of small module	$57 \times 57\,\mathrm{cm}^2$
Average pad size	$3.97\,\mathrm{cm}^2$
Detector active area	$114\,\mathrm{m}^2$
Radiator thickness	30 cm per layer
Detector radiation length	$< 4.2\,\%\, X_0$ per layer
Detector gas	Xe (85 %), CO_2 (15 %) Ar (80 %), CO_2 (20 %)
Depth of amplification region	7 mm
Depth of drift region	5 mm
Drift field	100 V/mm
Max. signal collection time	0.3 µs
Typical space point resolution at $p = 1\,\mathrm{GeV}/c$	~ 300 µm
Pion suppression at 90 % electron efficiency and $p \geq 1.5\,\mathrm{GeV}/c$	10 – 20
dE/dx resolution above $p = 1\,\mathrm{GeV}/c$	$\sim 25\,\%$

Performance Study for Dileptons in the Intermediate Mass Range (IMR)

IMR Di-Leptons

Dilepton spectra

Space-time integral of EM radiation

Different collision stages accessible in different mass regions

Low mass region (*M* < 1.1 GeV)
Access to in-medium spectral functions

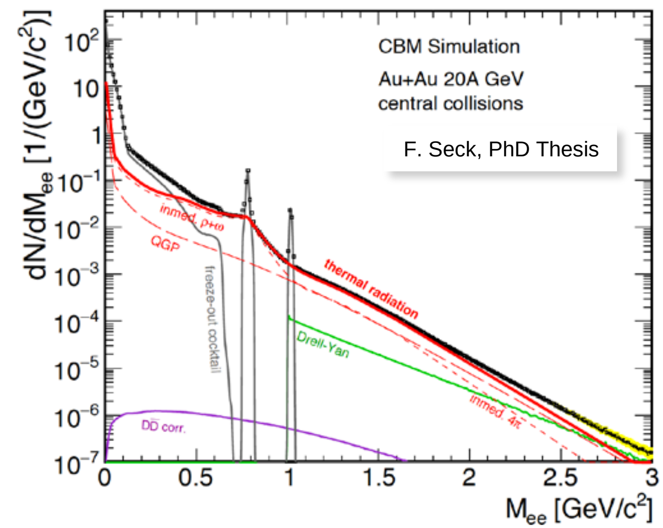
Intermediate mass region (*M* > 1.1 GeV)
Access to thermal medium radiation

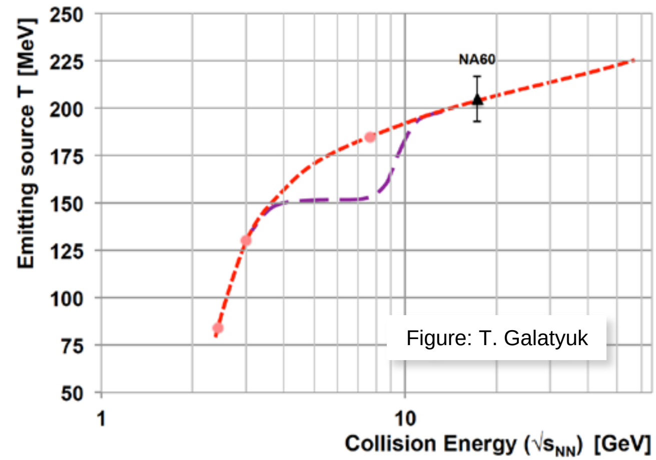
Excitation function of IMR

Extract T_{slope} from mass spectra

Monotonous decrease or possible indications for 1st order phase transition?

Challenging measurement!





Simulation Setup

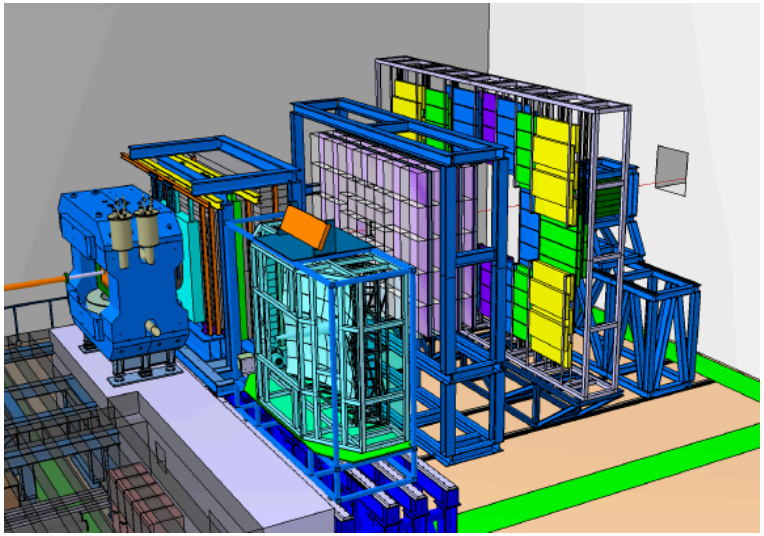
Software + Geometry
CbmRoot JUN16 Release

Default geometries of SIS100
sis100_electron_setup

TRD with four (default) and five layers

w/o MVD

Target thickness 25 μm



Reconstruction Parameters
Realistic TRD clustering

Latest RICH geometry,
digitization and reconstruction

Updated STS reconstruction

Simulation Input

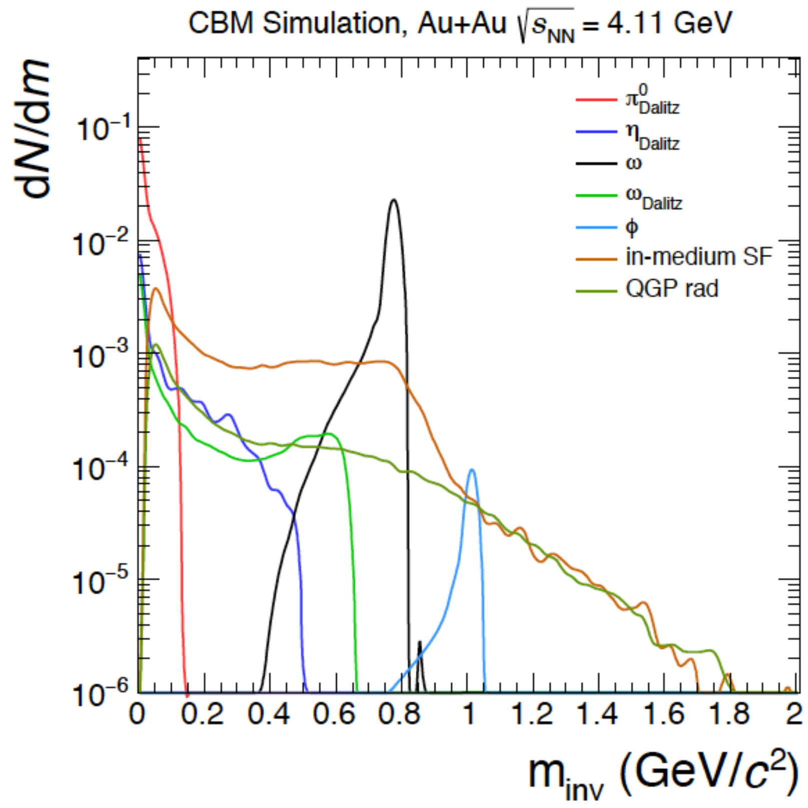
Central Au+Au at 8 *A*GeV
UrQMD background events

Di-electron signal
LMVM cocktail,
yields according to HSD prediction
(W. Cassing et al., Nucl. Phys. **A691** (2001) 753)

Thermal radiation
(T. Galatyuk et al., Eur. Phys. J. **A52** (2016) 131)

Generated via PLUTO
and added to UrQMD events

Source	$BR_{e^+e^-}$	Total multiplicities	
		p + Au	Au + Au
ρ^0	$4.72 \cdot 10^{-5}$	$3.4 \cdot 10^{-3}$	9.0
ω	$7.28 \cdot 10^{-4}$	$5.7 \cdot 10^{-3}$	19.0
ϕ	$2.97 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$	0.12
$J/\psi(1S)$	$5.97 \cdot 10^{-2}$	$5.1 \cdot 10^{-8}$	—
$\psi(2S)$	$7.89 \cdot 10^{-3}$	$1.3 \cdot 10^{-9}$	—
In-medium radiation	—	—	$2.2 \cdot 10^{-2}$
QGP radiation	—	—	$5.8 \cdot 10^{-3}$



Electron-ID

Pion suppression factor

Four TRD layers

ANN for RICH and TRD used

Requirements on reconstructed tracks:

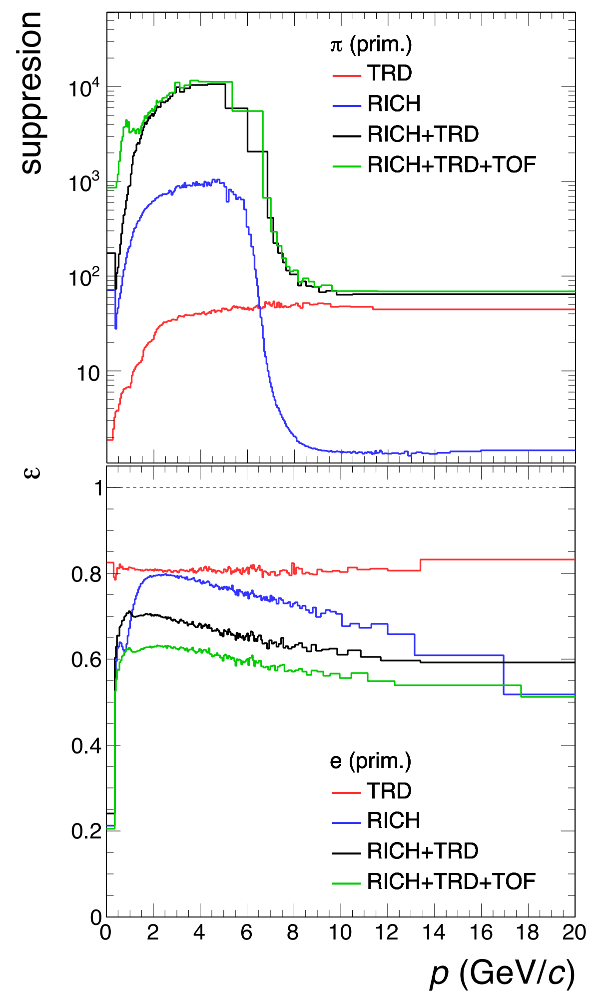
N_{hits}(STS) ≥ 6, N_{hits}(RICH) ≥ 6 and N_{hits}(TRD) ≥ 3

Detector combination	Momentum region	Electron efficiency	Pion suppression factor
TRD	$2-8\,\mathrm{GeV}/c$	80 %	30
	$>8\,\mathrm{GeV}/c$	80 %	50
	$2-8\,\mathrm{GeV}/c$	90 %	10
	$>8\,\mathrm{GeV}/c$	90 %	15
RICH+TRD+TOF	$2-8\,\mathrm{GeV}/c$	60 %	8×10^3
	$>8\,\mathrm{GeV}/c$	55 %	80
	$2-8\,\mathrm{GeV}/c$	70 %	5×10^3
	$>8\,\mathrm{GeV}/c$	65 %	20

Electron efficiency

TRD: tuned to const. 80 % for IMR analysis

RICH: 60 − 80 %, depending on momentum



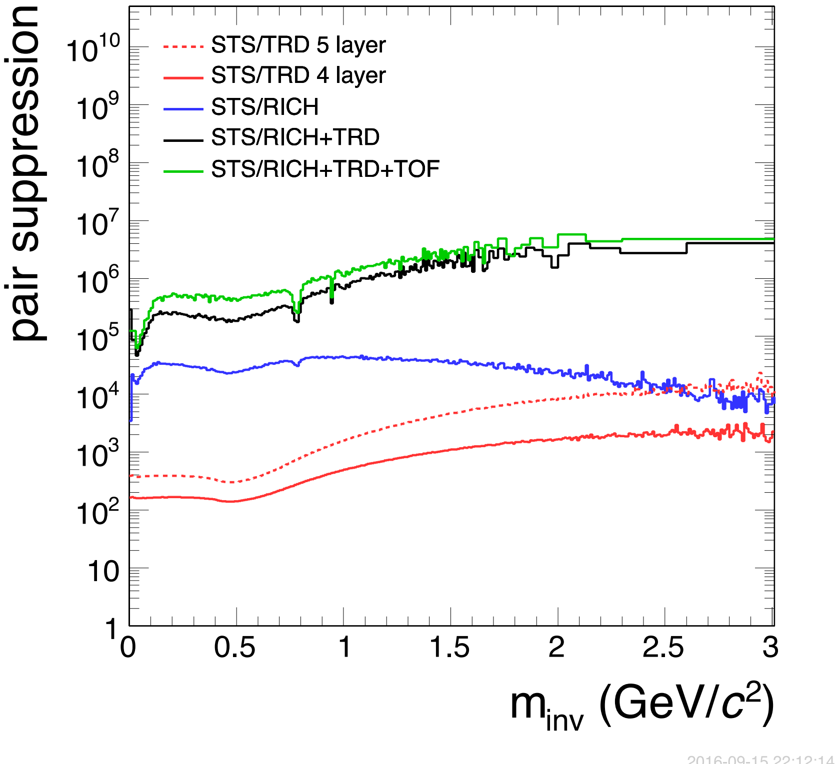
Electron-ID vs. Mass

Di-Electron pairs
UrQMD + di-electron cocktail

Pair suppression
TRD important for higher masses

5 layer TRD provides
same suppression factor
than RICH at $m_{inv} \approx 2.5$ GeV/c^2

4 layer TRD always below RICH
up to $m_{inv} = 3$ GeV/c^2



Invariant Mass Distributions

Central Au+Au at 8 *A*GeV

Total unlike-sign spectrum (red)

Signal contributions

Meson decays:

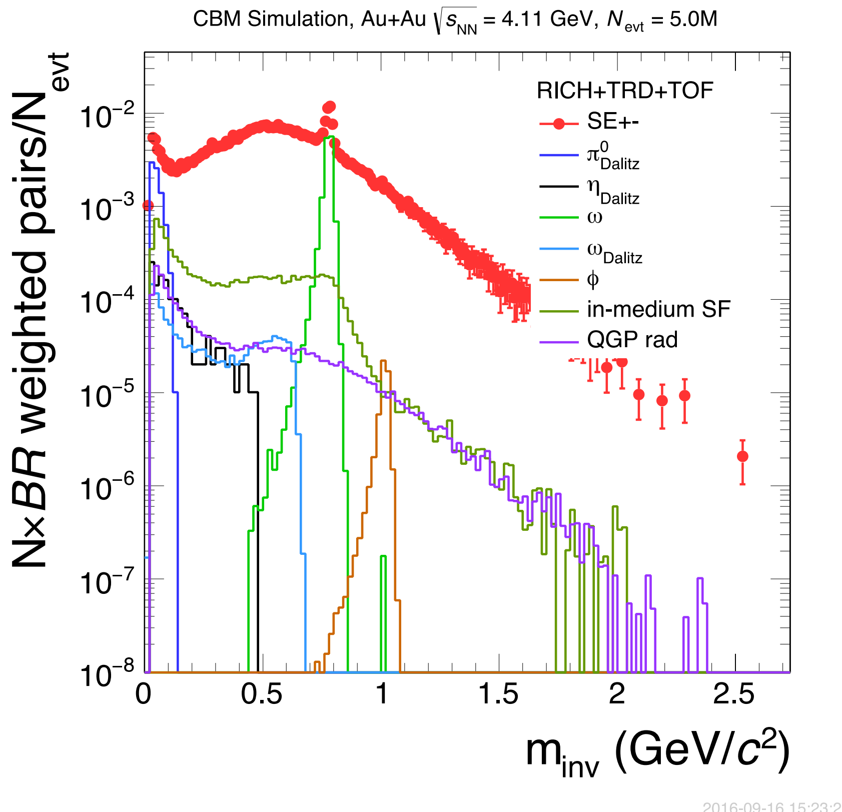
π^0_{Dalitz}, η_{Dalitz}, ω, ω_{Dalitz}, ϕ

Thermal components:

QGP radiation

+ in-medium spectral functions

Mass range	S/B 4 layers
$> 1\,\mathrm{GeV}/c^2$	$(1.4 \pm 0.3) \cdot 10^{-2}$
$1.0 - 1.1\,\mathrm{GeV}/c^2$	$(1.8 \pm 0.5) \cdot 10^{-2}$
$1.2 - 2.0\,\mathrm{GeV}/c^2$	$(1.2 \pm 0.4) \cdot 10^{-2}$



Invariant Mass Distributions

Central Au+Au at 8 *A*GeV

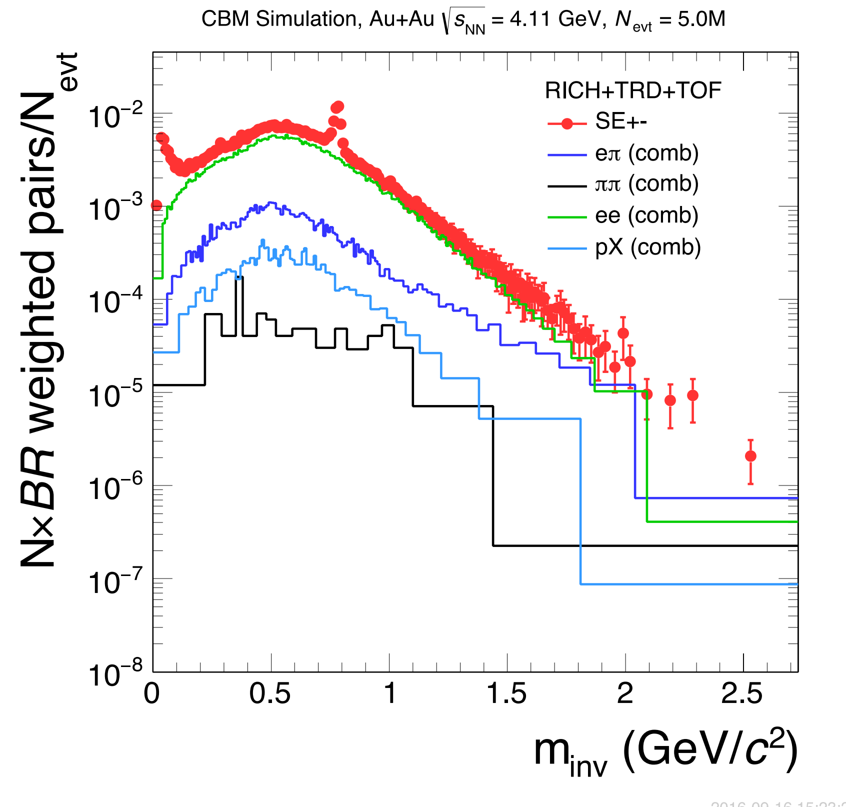
Total unlike-sign spectrum (red)

Background contributions

ee-Combinations dominate
up to $m_{inv} \approx 2$ GeV/c^2
Cannot be reduced by better e-ID

eπ-Combinations on same level than ee above $m_{inv} \approx 2$ GeV/c^2

ππ- and pX-combinations are minor contributions



Thermal Component

Extraction of thermal component

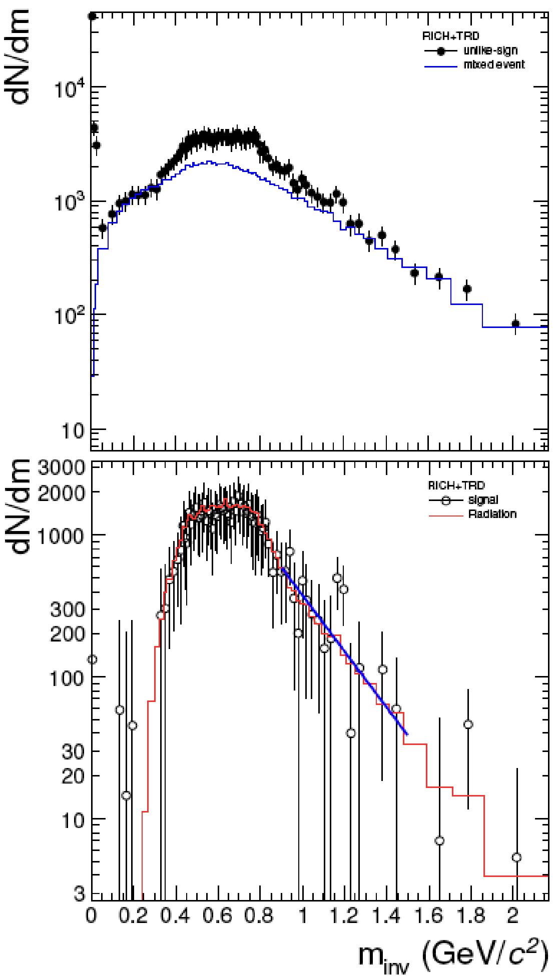
Full simulation at realistic *S/B* not possible

Compare to simulation with enhanced *S/B*
(by factor ~10: *S/B* ~ 0.2 for m_{inv} > 1 GeV/c^2)
⇒ 2.5·10⁶ evts. = $S/\sqrt{S+B} \approx 3.5$

Subtraction of mixed events background
⇒ rest agrees well with MC input distribution

Fit with $\exp(-m_{inv}/T_{eff})$ ⇒ T_{eff} = 216 ± 64(stat.) MeV
Input: T_{eff}(MC) = 230 MeV

⇒ Analysis feasible for significances ≥ 10



Realistic scenario

S/B ~ 10^{-2} und *S*/evt. ≈ $6\cdot10^{-6}$
Sig. ≥ 10 ⇒ 10^{10} (10^{11}) CN (MB) Au+Au evts.
(30 h data taking at 1MHz)

Invariant Mass Distributions

Central Au+Au at 8 *A*GeV

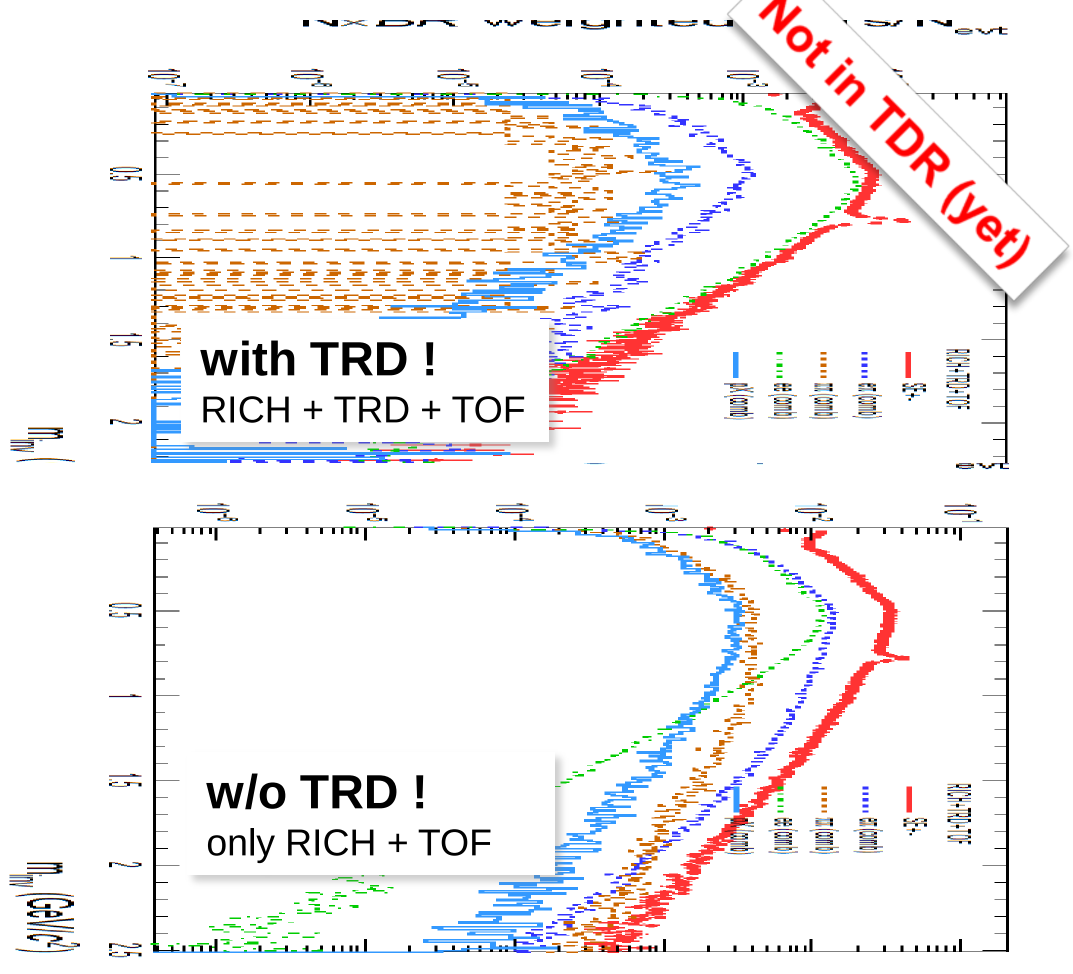
Total unlike-sign spectrum (red)

(New analysis, based on likelihood instead of ANN)

Comparison:
with and w/o TRD

Unlike-sign spectrum dominated by ππ and eπ combinations at higher masses w/o TRD

⇒ Background higher by ~ two orders of magnitude!
(at m_{inv} = 2 GeV/c^2)



Electron-ID: Five TRD Layers

Pion suppression factor

Five TRD layers

ANN for RICH and TRD used

Requirements on reconstructed tracks:

$N_{hits}(STS) \geq 6$, $N_{hits}(RICH) \geq 6$ and $N_{hits}(TRD) \geq 3$

Detector combination	Momentum region	Electron efficiency	Pion suppression factor
TRD	$2-8\,\mathrm{GeV}/c$	80 %	30
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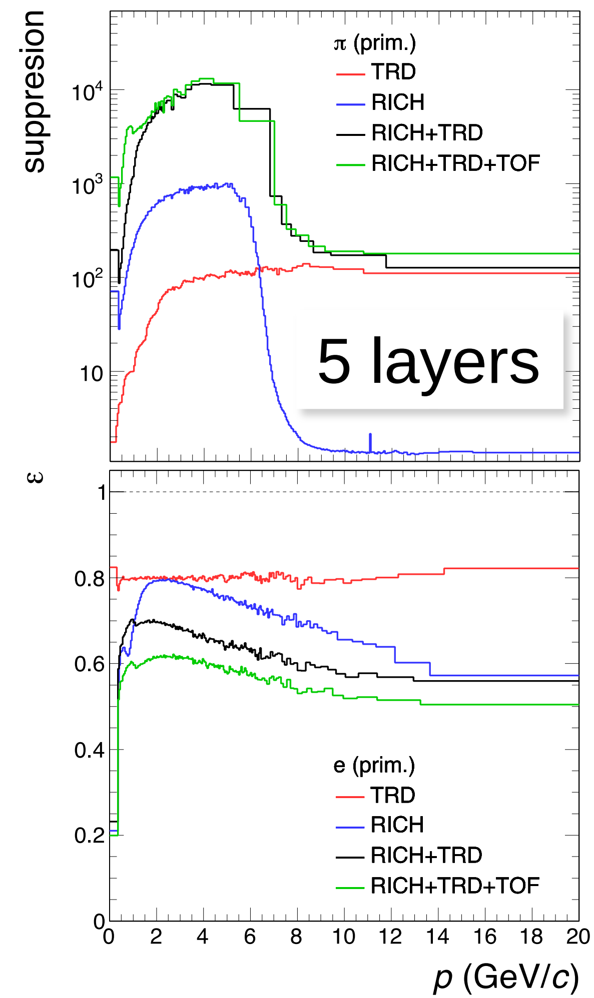
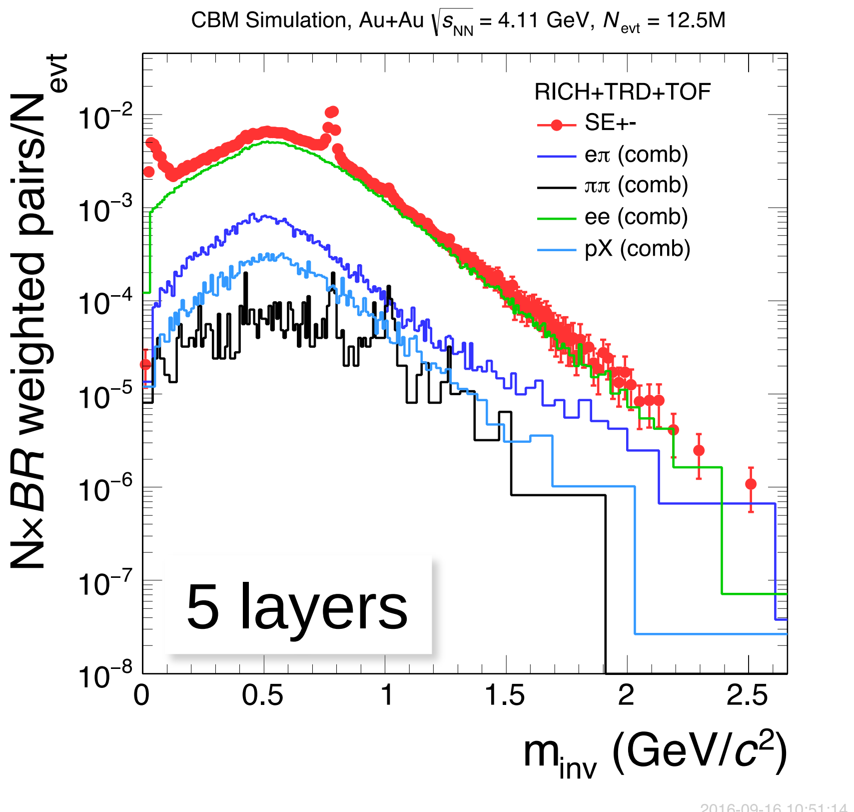
RICH+TRD+TOF	$2-8\,\mathrm{GeV}/c$	60 %	8×10^3
	$>8\,\mathrm{GeV}/c$	55 %	80
	$2-8\,\mathrm{GeV}/c$	70 %	5×10^3
	$>8\,\mathrm{GeV}/c$	65 %	20
TRD(5L)	$2-8\,\mathrm{GeV}/c$	80 %	70
	$>8\,\mathrm{GeV}/c$	80 %	130
RICH+TRD(5L)+TOF	$2-8\,\mathrm{GeV}/c$	60 %	8×10^3
	$>8\,\mathrm{GeV}/c$	55 %	230



Invariant Mass Distributions

Four vs. five TRD layers
Moderate improvement at higher masses with five layers due to slightly reduced eπ-background

No qualitative difference (dominance of ee-background)



Invariant Mass Distributions

Four vs. five TRD layers

Moderate improvement at higher masses with five layers due to slightly reduced eπ-background

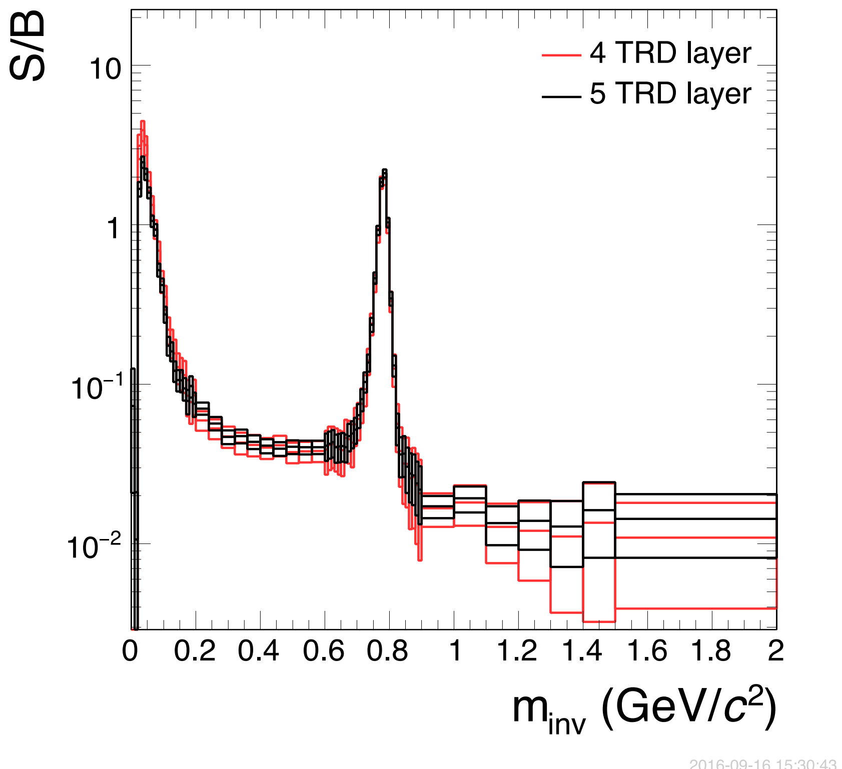
No qualitative difference (dominance of ee-background)

No significant improvement in signal-to-background ratios

Mass range	S/B 4 layers	S/B 5 layers
$> 1\,\mathrm{GeV}/c^2$	$(1.4 \pm 0.3) \cdot 10^{-2}$	$(1.6 \pm 0.2) \cdot 10^{-2}$
$1.0 - 1.1\,\mathrm{GeV}/c^2$	$(1.8 \pm 0.5) \cdot 10^{-2}$	$(1.9 \pm 0.4) \cdot 10^{-2}$
$1.2 - 2.0\,\mathrm{GeV}/c^2$	$(1.2 \pm 0.4) \cdot 10^{-2}$	$(1.4 \pm 0.3) \cdot 10^{-2}$

$$\frac{\Delta S}{S} \approx \frac{\Delta B}{B} \cdot \frac{B}{S}$$

⇒ $\Delta S/S = 5 - 10\%$ (with $\Delta B/B = 0.1\%$)



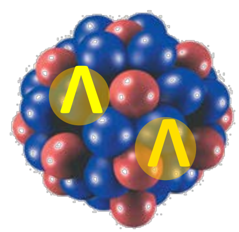
Performance Study for Fragment Identification

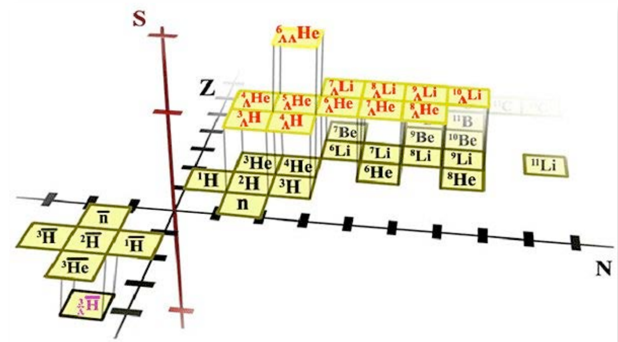
Hypernuclei and Fragments

3rd Axis of nuclide chart
(Double-)hypernuclei

Information on $\Lambda\Lambda$ interaction
($\rightarrow$ neutron stars)

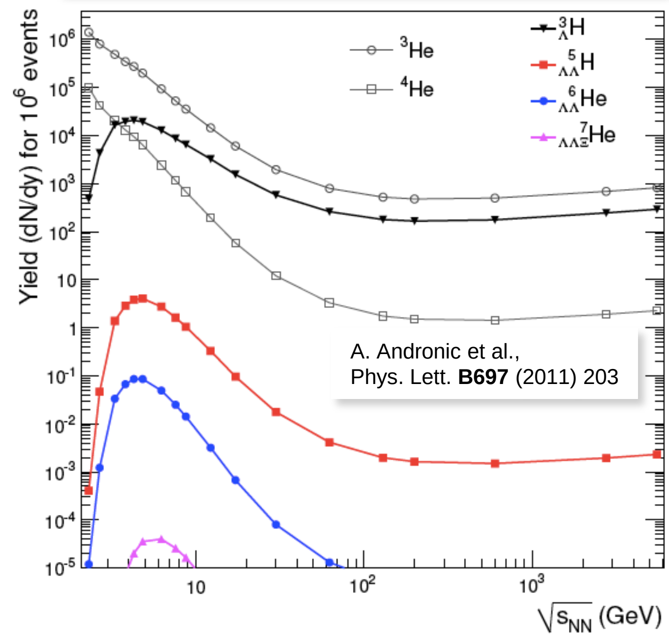
High event statistics needed
Production favored by high ρ_B





Fragment ID mandatory
Separation of d and ^{4}He
(not possible with TOF alone)

E.g.:
$_{\Lambda\Lambda}{}^{6}He \rightarrow {}_{\Lambda}{}^{5}He + p + \pi^-$
$_{\Lambda}{}^{5}He \rightarrow {}^{4}He + p + \pi^-$
would be indistinguishable from
$_{\Lambda}{}^{3}He \rightarrow d + p + \pi^-$ w/o TRD



Simulation Input

Central Au+Au at 8 *A*GeV

5×10^6 UrQMD background events

Four TRD layers

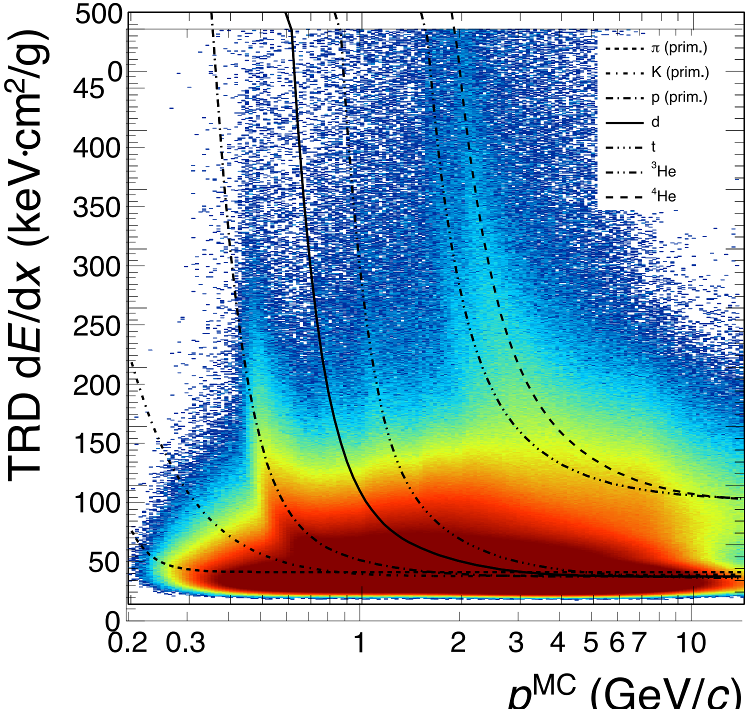
Fragment signal

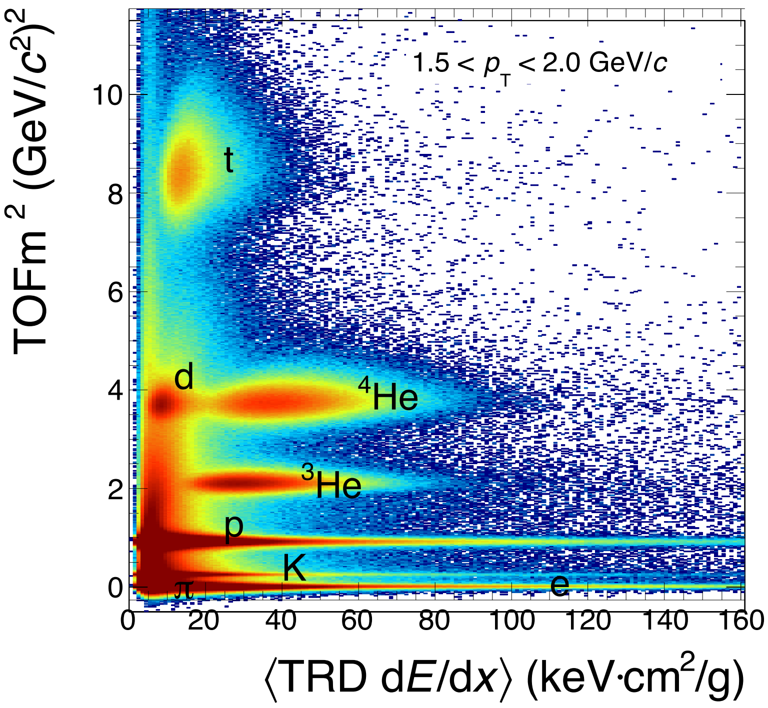
d, t, ^{3}He and ^{4}He added to background events

Flat p_t distributions ($0 < p_t < 3$ GeV/c)

Rate: 1 particle/event

Fragment-ID



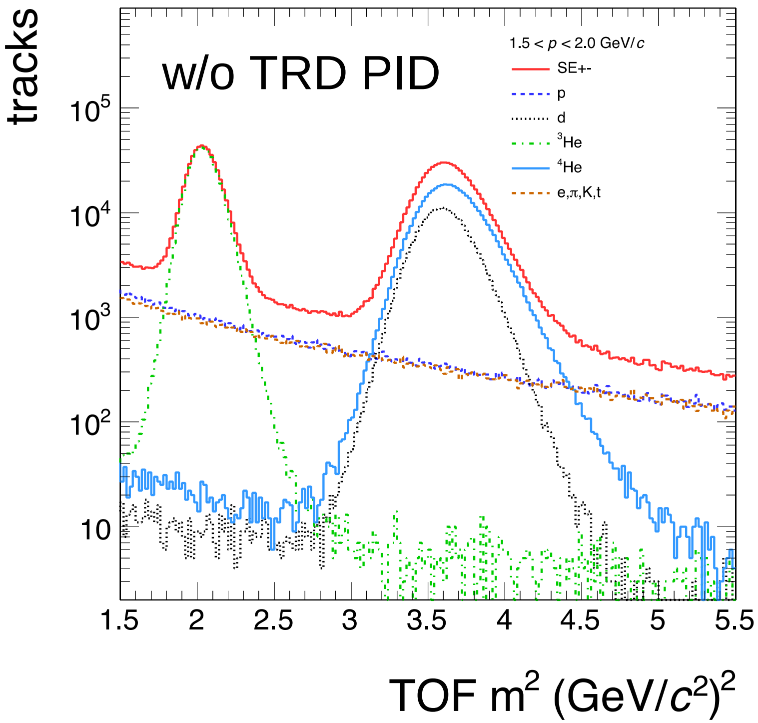


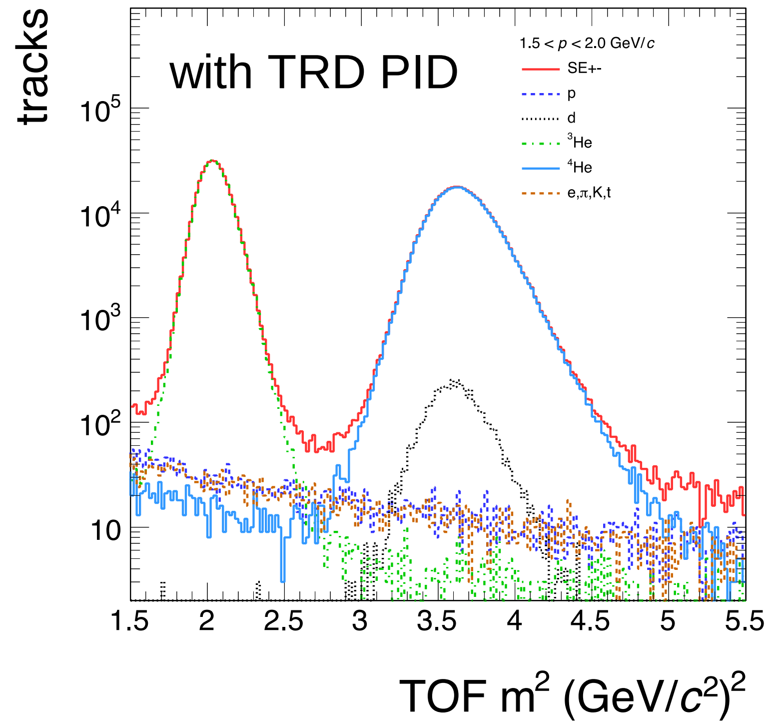
Specific energy loss in TRD gas (Xe/CO_2)

⟨*dE/dx*⟩-values, averaged over 3−4 layers

Clear separation of d and ^{4}He possible

Fragment-ID





Mass distributions in TOF w/o and with TRD

Selection of ^{4}He with TRD $\langle dE/dx \rangle$ for $1.5 < p < 2.0$ GeV/c

Reduction of other background in addition

Fragment-ID

⟨*dEdx*⟩-Signals in TRD for d and ^{4}He

Resolution σ_i from fits with Gaussians

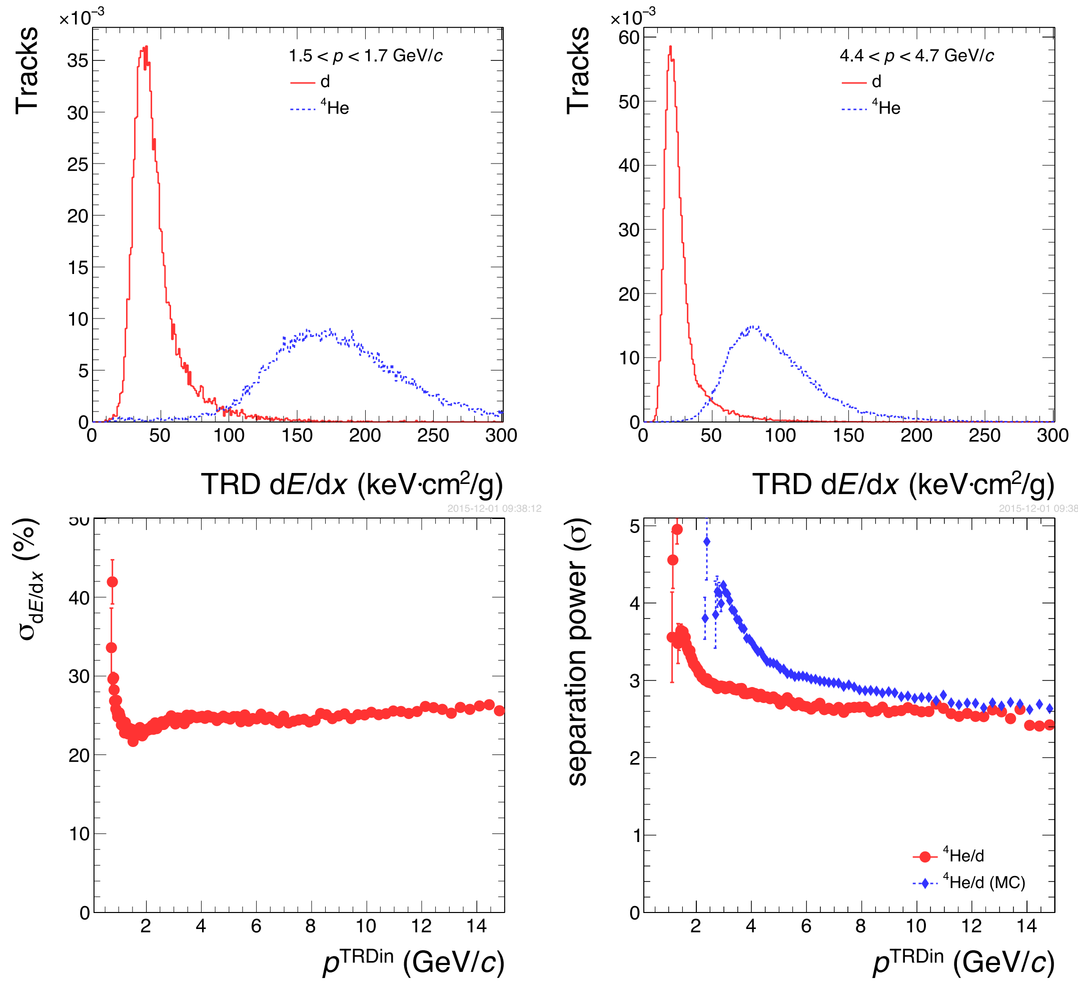
⇒ ~ 25 % resolution above p = 1 GeV/c

Separation power

$$S_{ij}(p) = \frac{\langle dE/dx\rangle_i(p) - \langle dE/dx\rangle_j(p)}{\sigma_i(p)}$$

Separation of $\sigma \gtrsim 2.5$

(higher if charge information is used in momentum determination)



Performance Study for J/ψ-Measurements

J/ψ Measurements at SIS100

Quarkonia in heavy-ions

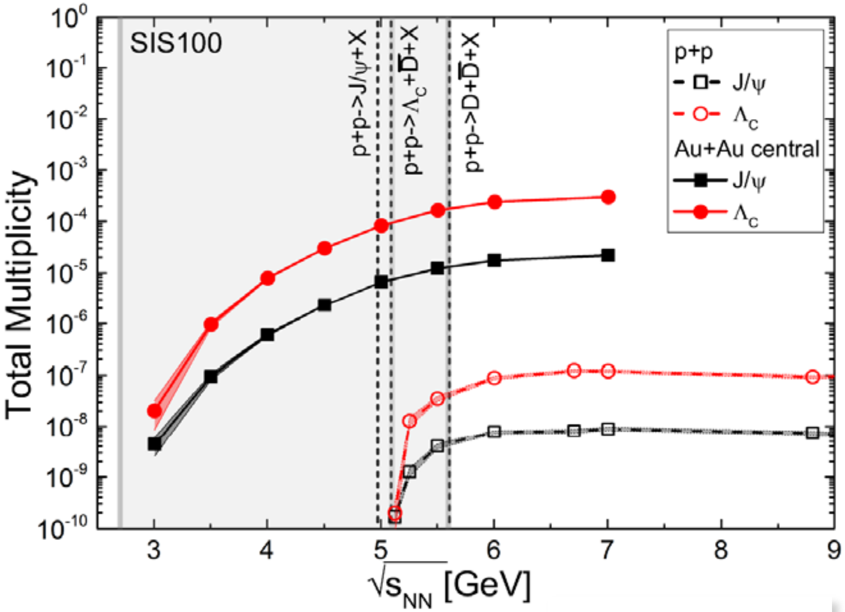
Important probe for deconfinement

"J/ψ-Suppression"

(T. Matsui and H. Satz, Phys. Lett. **B178** (1986) 416)

Observed at SPS and higher energies. How does this evolve towards lower energies?

J/ψ production below threshold: new model predictions



J. Steinheimer et al., arXiv:1605.03439v1

Proton-Nucleus measurements

Understanding of elementary production processes

Interaction with cold nuclear matter

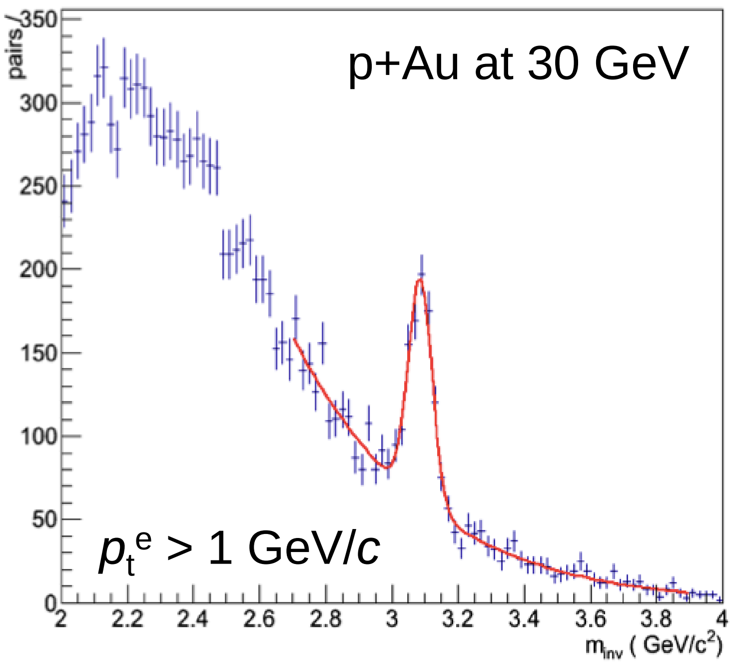
J/ψ Measurement in p+Au

Simulation input

p+Au Collisions at 30 GeV
UrQMD background events

J/ψ signal added to background

Yield scaled to HSD prediction
$1.0 \cdot 10^{-8}$ J/ψ/evt.
(W. Cassing et al., Nucl. Phys. **A691** (2001) 753)



Analysis

Electron-ID with RICH + TRD (4 layers)

N_{hits}(STS) ≥ 5, N_{hits}(TRD) ≥ 3, $p_t^e > 1$ GeV/c

Results corresponds to $2.5 \cdot 10^{13}$ collected events
⇒ 30 days of data taking at 10 MHz

$N_{J/\psi} \approx 600$, $S/B \approx 1.25$

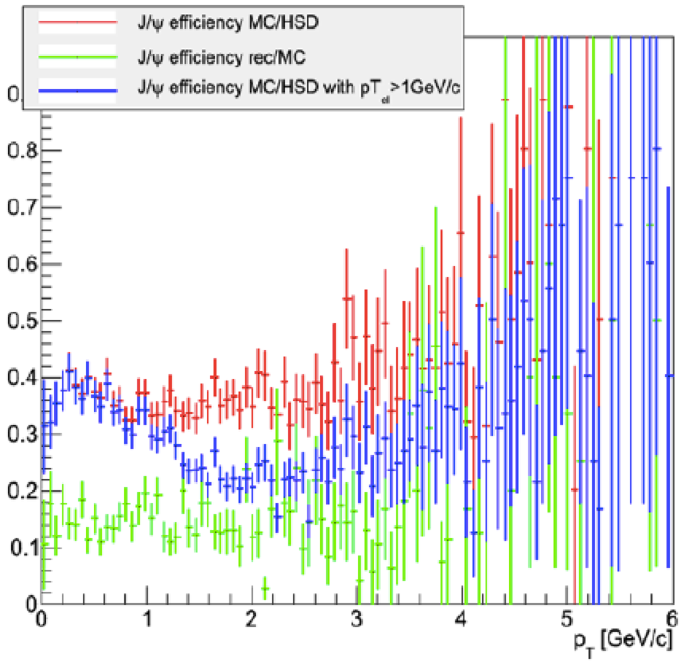
J/ψ Measurement in p+Au

J/ψ Reconstruction efficiency

Pure acceptance
(red symbols) ≈ 35 %

Additional p_t cut on
electrons (blue symbols)
⇒ ~ 20 % above p_t(J/ψ) = 1.5 GeV/c

Inefficiencies of reconstruction
⇒ ~ 15 % for all momenta



Conclusions

Physics cases for the TRD in CBM at SIS100

Intermediate mass dielectrons

Measurement of fragments

J/ψ in p+A and A+A (sub-threshold)

Design parameters of the TRD

Electron-ID: pion suppression factor ~ 15 at high p_t (@ 90% e-efficiency)
⇒ four layer setup sufficient for physics cases

Also provides sufficient resolution in *dE/dx* (~ 25 %)

Important: fast detector, since observables are statistics hungry
(interaction rates 1 − 10 MHz)

Low material budget and good point resolution (~ 300 μm)
to allow for efficient track matching between STS and TOF

BACKUP